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(54) Abstract Title
Attachment device using a shaped memory alloy for a cryogenic satellite tank

(57) Attachment device for a cryogenic satellite tank comprises a first member 1 and a second member 2 connected by a shape memory alloy (SMA) member 3. The first and second members 1, 2 are connected together by the SMA 3 when it is in an austenitic state but the connection between the first and second members 1, 2 is loosened when the SMA 3 expands in its martensitic state following cooling in space. This allows reduced surface pressure and reduced surface contact, resulting in reduced thermal flow between the first and second members. The SMA member 3 may be formed as a bolt and/or a ring 11 (and 19, figure 4) and made of a NiTiCuFe alloy.

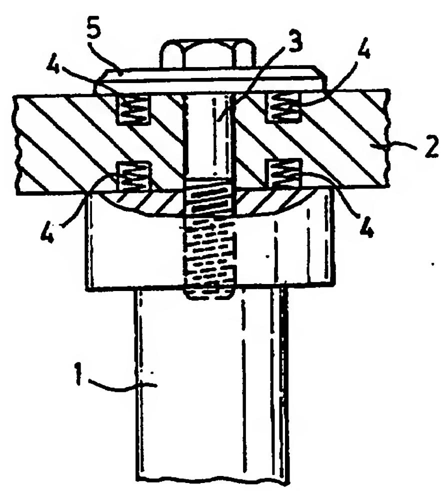

Fig.1

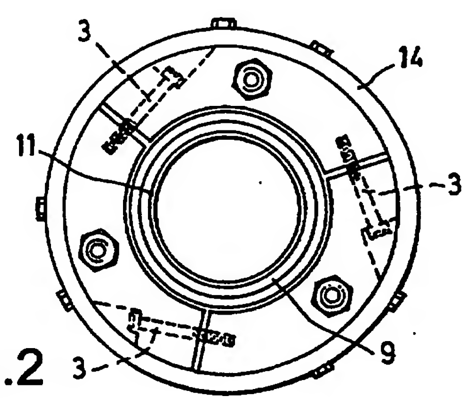

Fig.2

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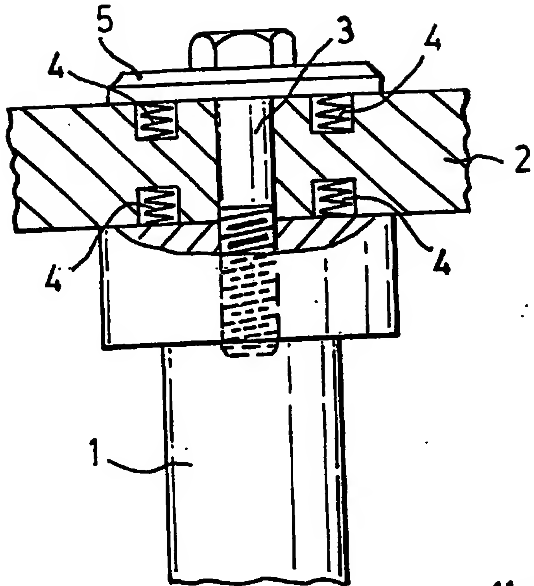

Fig.1

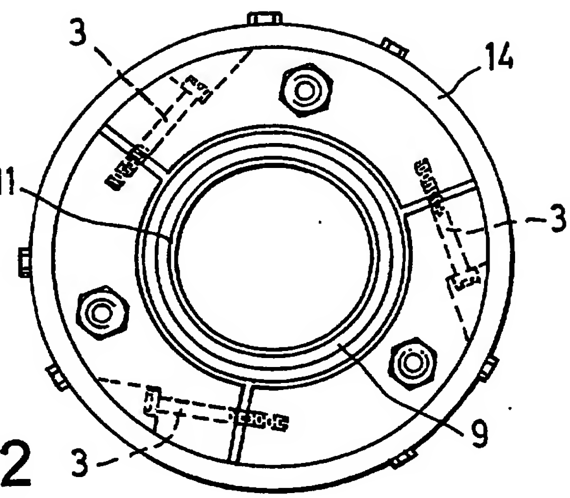

Fig.2

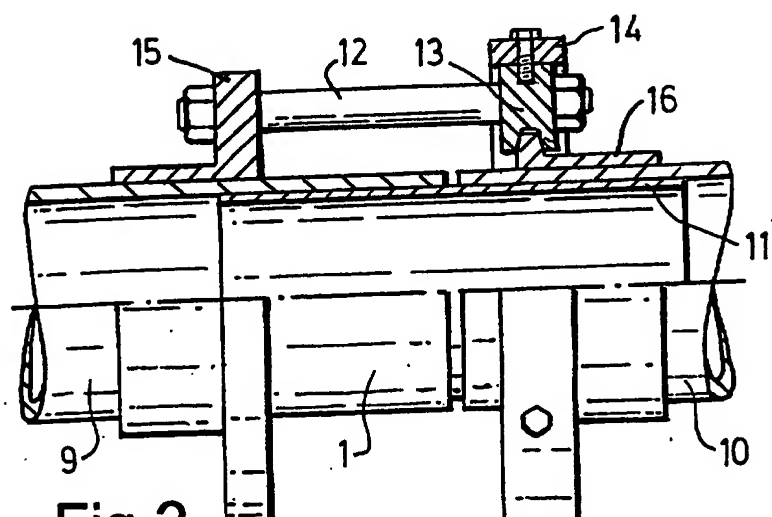

Fig.3

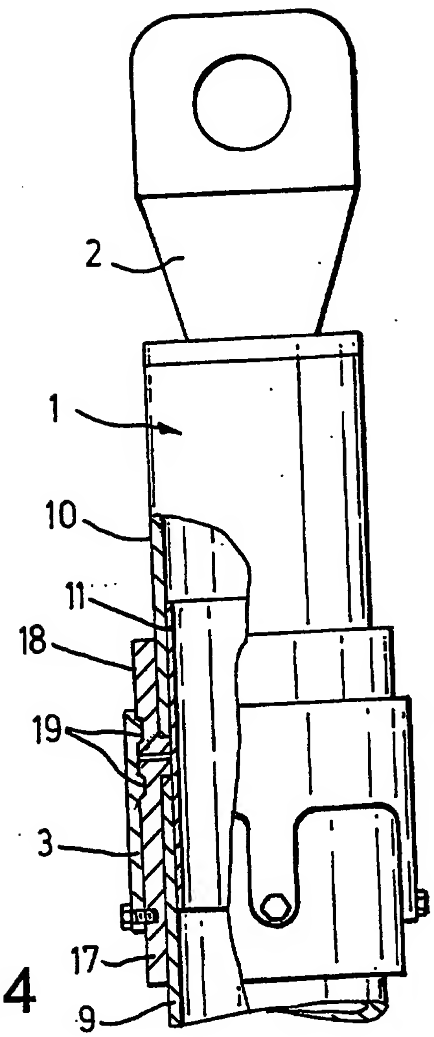

Fig.4

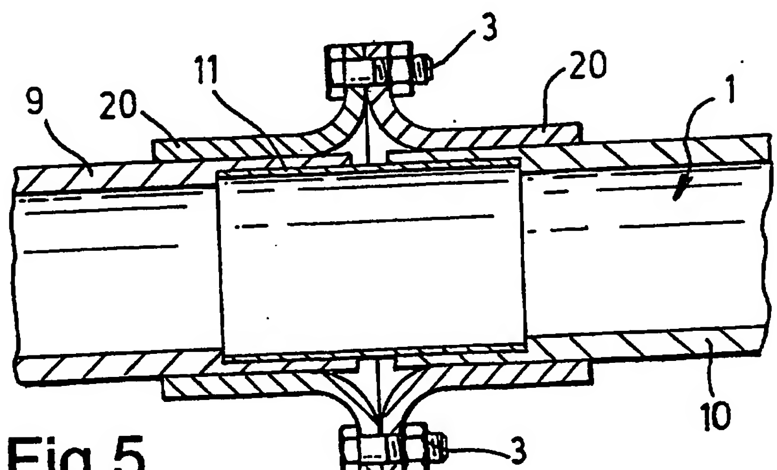

Fig.5

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Attachment Device for a Cryogenic Satellite Tank

The present invention relates to an attachment device for a cryogenic satellite tank.

The service life of a satellite equipped with a cryogenic tank is determined to a large extent by thermal flow to the cryogenic tank. The thermal flow emanates from the warmer satellite via a tank attachment device, and flows to the tank. This thermal flow results in an increase in pressure in the tank. The pressure increase is compensated for by partial draining off of the tank's contents.

As a result of the thermal flow via the attachment device, the achievable cooling temperatures for both active and passive cooling are limited resulting in increased coolant consumption.

Substantial mechanical loads occurring during launch of the satellite prevent adequate reduction in material of the attachment device, so that optimised design of the attachment device from the point of view of material cannot adequately reduce the thermal flow via the attachment device, even if materials of little thermal conductivity are used.

A device for holding a storage container by means of tensile stress within an object particularly in the field of space technology, is known from EP 0 584 679 B1. The known device ensures a stable connection between a storage container and an object during the start phase at comparatively low mechanical loads. It also ensures that the holding device between the storage container and the object is of low thermal conductivity. This is achieved by using shaped parts made of shape memory alloy (SMA).

An object of the invention is to provide an attachment device for a cryogenic satellite tank which provides for adequate stiffness and strength at reduced thermal conductivity, is simple in design and technically easy to produce, is not prone to malfunction and thus has low maintenance requirements.

The invention provides an attachment device for a cryogenic satellite tank comprising at least one connection between a support element and a connecting component and at least one SMA element, characterised in that the SMA element in the austenitic state through the direct contact between one end of a support element and one end of a connecting component interconnects these in a non-positive way; and the SMA element during cooling in space and the resulting martensitic state, due to elongation or widening, loosens or partially disconnects this non-positive connection, and due to the resulting reduced surface pressure and reduced contact surface, reduces the thermal flow between the support element and the connecting component. The invention also provides an attachment device for a cryogenic satellite tank comprising at least one connection between the support element and the connecting component and at least one SMA element, characterised in that the connection between the support element and the connecting component comprises a support element comprising two sections, with a thermally controlled connection between them; in its austenitic state the SMA element connects a support element and a connecting component in a non-positive way; and the SMA element during cooling in the space environment and the resulting martensitic state, as a result of elongation or widening, loosens or partially disconnects this non-positive connection and due to the resulting reduced surface pressure and reduced contact area, reduces the thermal flow between the support element and the connecting component. Advantageous embodiments are set out in the sub-claims.

The thermal conductivity between two objects pushed against each other is determined substantially by their surface pressure and contact area. The attachment device according to the invention uses shape memory alloy members, which extend significantly automatically following the rocket start in the cold space environment, thus reducing the surface pressure at the respective connection points and partially breaking

the contact. Consequently, the thermal flow via these contact points is reduced or completely interrupted. The resulting reduction in rigidity of the attachment device can be adequate for use in the space environment if the connection points have been suitably designed. Alternatively, apart from the connection points controlled by SMA members, the attachment device comprises additional continuously rigid attachment means which ensure adequate rigidity and maintenance of the tank alignment.

The decisive characteristic of SMA members is the thermoelastic transformation from a high-temperature configuration austenite to a low-temperature configuration martensite. When such an element cools down, below a limit temperature T_{Ms}, the formation of martensitic phases commences. This process is completed on further cooling at a temperature T_{Mf}, when a complete martensitic state is attained. When heated from the martensitic state, above a temperature T_{Ar}, austenitic phases form. This transformation to the austenitic phase is completed when the temperature T_{Ar} is reached.

Thermomechanical training of the SMA members results in a cyclic change in length both during heating and during cooling without any adjacent load: the so-called two-way effect. This training is necessary to achieve an additional change in length of the connection points of the attachment device beyond the mechanical balance which is necessary for extension according to the invention. The entire achievable change in length of the SMA members after carrying out thermomechanical training ranges from approximately 1.5% to approximately 4%.

The SMA members are preferably made from a NiTi-based alloy, but SMA alloys with a different basis can be used as long as they satisfy the transformation temperatures and changes in lengths according to the invention. In the case of NiTi-base alloys, quaternary alloys such as NiTiCuFe or NiTiCuCr are used.

The composition of these alloys is selected such that the transformation temperature for completion of the austenite formation T_{Ar} is less than 0 degree C, so that the SMA elements of the attachment device are fully within the austenitic state for the ambient

temperatures during the start phase, during which the largest acceleration forces act upon the attachment device. The final temperature for martensite formation T_{Mf} is set to a value above the temperature at the attachment device in space, this temperature depends on the respective satellite emission which is typically between 2 K and 220 K.

In the austenitic state, the SMA material according to the invention has a tensile strength from 700 MPa to 980 MPa and an E-modulus from 83 GPa to 100 GPa. The mechanical properties of the SMA material are that, if it is suitably dimensioned, it can easily absorb and transmit the forces acting upon the attachment device during rocket start. In the martensitic state the material is relatively soft.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Fig. 1 shows a connection between a support element and a connecting component comprising an SMA bolt and pressure springs;

Fig. 2 shows a connection between a support element and a connecting component comprising an SMA bolt and additional SMA members;

Fig. 3 shows a connection between a support element and a connecting component comprising a divided support element and a stud bolt connection with SMA members;

Fig. 4 shows a connection between a support element and a connecting component comprising a divided support element which is held together by an SMA split taper socket; and

Fig. 5 shows a connection between a support element ad a connecting component with a divided support element comprising an SMA bolt connection.

In Fig. 1, the connection between a support element and a connecting component for an attachment device comprises a support element 1, a connecting component 2, an SMA (shaped memory alloy) member 3, compression springs 4 and a washer 5.

During cooling in orbit the SMA member 3, in the form of a bolt, and the compression springs 4 inserted into the connecting component 2, separate the washer 5 from the connecting component 2, as well as separating the connecting component 2 from the end of the support element 1 located on the connection side. After the elongation of the SMA member 3 occurs, thermal flow via the connection between the support element 1 and the connecting component 2 is reduced, due to the lack of surface pressure of direct contact between the end of the support element 1 and the connecting component 2 and between the connecting component 2 and the washer 5 resulting in thermal flow only taking place via the compression springs 4 and via lateral resting of the bolt in the drill hole. As a result of elongation of the bolt and spring action, relative displacement of the support element 1 or of the connecting component 2 occurs; minimal forces can then only be transmitted via the connection between the support element and the connecting component by means of the compression springs 4.

The support element 1 can, for example, be made as a strut or as a closed-off tube, with a threaded hole for the bolt. The connecting component 2 can, for example, be a flange of the attachment device, on the side of the satellite. The washer 5 is designed such that on the side of the bolt head, compression springs 4 inserted in the connecting component 2 can act upon said washer. The compression springs 4 are designed as spiral springs and are inserted in both facing surfaces of the connecting component 2. Alternatively, other suitable compression springs are used.

The connection between the support element and the connecting component as described above, provides the following advantages: an SMA member which is simple to produce can be used; the connection can be used with support elements of small diameter; the connection makes for simple installation and can transmit very substantial forces in a warmer, austenitic state.

The connection between the support element and the connecting component, as shown in Fig. 2, comprises a support element 1, a connecting component 2, an SMA member 3, additional SMA members 6, a connection sleeve 7 and an insert 8.

SMA member 3, in the form of a bolt, connects the insert 8 to the connecting component 2 via a through-hole. The insert 8 is in turn firmly connected to the connection sleeve 7 by means of the additional SMA members 6. The additional SMA members 6 are, for example, configured as stays and are fastened by means of screws or rivets at the connection sleeve 7 and the insert 8. The support element 1 is seated with a positive fit in the connection sleeve 7 and fastened therein by means of adhesive or by shrinking-on.

In the warmer, austenitic state, the support element 1 and the connecting component 2 in the above described connection are firmly connected. During cooling, both the SMA member 3 in the form of a bolt, and the additional SMA members 6 in the form of stays, elongate. Consequently both the bolt head and insert 8 are separated from the connecting component 2. The thermal flow remaining in the connection can then only take place via the supporting points of the bolt in the through-hole of insert 8.

In the cooled state this connection cannot transfer any forces, i.e. to maintain fastening of the cryogenic satellite tank in space, the attachment device must comprise additional other connections between the support element and the connecting component, to allow fastening and permit transmission of forces even in the cooled state.

In the connection between the support element and the connecting component described above in relation to Fig. 2, simple to produce SMA members can be used. The normal support elements of the known attachment devices can be used and in the warmer austenitic state, very substantial forces can be transmitted.

Fig. 3 shows a connection between the support element and the connecting component in which a thermally controllable connection point is completely located within the support element 1. The connection comprises a stud bolt connection. The connecting component 2 is connected in the conventional way to one of the support element sections. For reasons of simplicity, Fig. 3 does not show the connecting component 2 and the connection of the connecting component to the support element section.

The stud bolt connection of the connection between the support element and the connecting component comprises two support element sections 9 and 10 of the tubular support element 1 which is interrupted at the connection point, a bridging element 11, several stud bolts 12, a stud bolt sleeve 15, a clamping ring 13, a split taper socket 16, an SMA ring 14 and SMA members 3.

The stud bolt sleeve 15 is fastened on one of the support element sections 9 or 10. The split taper socket 16 is fastened on the other support element section, e.g. by means of adhesive or by shrinking-on. The split taper socket 16 accommodates the clamping ring 13 via a conical tongue and groove connection so that it is fastened in an axial direction on the support element section in its clamped state. The clamping ring 13 comprises individual sections and is clamped by means of the SMA members 3 in the form of bolts, resulting in contraction of the clamping ring. The clamping ring 13 comprises drill holes through which one of the threaded ends of the stud bolts 12 protrudes. The other end of the stud bolts 12 is attached in a drill hole of the stud bolt sleeve 15. A nut is screwed onto the end of the stud bolts 12 which protrudes from the clamping ring 13. In this way the stud bolt connection is tightened.

In addition to the stud bolt connection, the two support element sections 9 and 10 are fastened to each other by means of a bridging element 11. The thermal conductivity of the bridging element 11 is less than that of the stud bolt connection. The bridging element can also only transmit smaller loads than the stud bolt connection. The three elements of the clamping ring 13 are connected to the SMA ring 14 via attachment bolts.

During cooling in space, the SMA members 3 in the form of bolts, elongate, and the SMA ring 14 widens. Consequently the conical tongue and groove connection between the clamping ring 13 and the split taper socket 16 evenly and completely disengages, thus impeding thermal flow via the stud bolt connection, between the support element sections 9 and 10 considerably.

This connection is advantageous in that it can transmit substantial forces in the warmer austenitic state.

In the embodiment shown, three stud bolts are distributed evenly around the circumference of the stud bolt connection; alternative numbers of stud bolts - from one stud bolt onwards - are possible.

The connection between the support element and the connecting component shown in Fig. 4 also comprises a thermally controllable connection point which is completely situated within the support element 1. The connecting component 2 is firmly connected to one of the support element sections in the conventional way.

The thermally controllable connection of the connection between the support element and the connecting component comprises the two support element sections 9 and 10 of a tubular support element 1 which is interrupted at the connection point, a bridging element 11, an SMA member 3 configured as a split taper socket, and two snap ring sleeves 17 and 18.

The snap ring sleeves 17 and 18 are fastened to the ends of the support element sections 9 and 10 by means of adhesive or by shrinking-on or other suitable means. On one of the snap ring sleeves 17 or 18 the SMA member 3 in the form of a split taper socket is fastened by bolts in such a way that it protrudes from the end of the respective support element section 9 or 10. On the interior surface of the socket the SMA member 3 comprises two, annular projections 19 axially spaced from one another. In assembled

support element sections 9 and 10 the annular projections 19 protrude in respectively arranged grooves on the fastened snap ring sleeves 17 and 18, thus comprising a tongue and groove connection on each support element section. When the connection is established, the SMA member 3 must temporarily be elongated by cooling to allow the projections 19 to interact with the grooves.

In addition, the two support element sections 9 and 10 are fastened to each other by means of a bridging element 11. The thermal conductivity of the bridging element 11 is less than that of the split taper socket but the bridging element only transmit smaller loads than the split taper socket.

During cooling in space, the SMA member 3 which is a split taper socket, widens. Consequently the connection between the SMA member 3 and the snap ring sleeves 17 and 18 disengages, thus impeding thermal flow between the support element sections 9 and 10 via the split taper socket considerably.

Fig. 5 shows a connection between the support element and the connecting component, whose controllable connection point is completely situated within the support element 1, as is the case in both previously described embodiments. The connecting component 2 is firmly connected in the conventional way to one of the support element sections. For reasons of simplicity this is not shown.

The thermally controllable connection of the connection between the support element and the connecting component comprises two support element sections 9 and 10 of a tubular support element 1 interrupted at the point of connection, a bridging element 11, two connection sleeves 20 and two SMA members 3 in the form of bolts. As an alternative, it is also possible to use more than two SMA members 3.

The connection sleeves 20 are fastened by adhesive, by shrinking-on or other suitable means. The connection sleeves 20 are arched in a flange-like manner towards the free end of the support element sections at the ends of the support element sections 9 and 10

to be connected. The sleeves 20 have axially aligned drill holes in the arched margins. The SMA members 3 in the form of bolts, are inserted through the holes and further comprise nuts. The support element sections 9 and 10 are fastened by tightening these screw connections and are pre-tensioned against the elasticity of the material. Fastening of the connection sleeves 20 to the support element sections 9 and 10 is such that, without the tightened SMA members 3, they do not contact each other via their flange-lie arched margins. Instead of the arching at the ends, the connection sleeves can comprise a joined flange.

During cooling in space, the SMA members 3 in the form of bolts, elongate. Consequently, due to the elasticity of the pre-tensioned arched structures or the flanges, the contact between the arched ends of the connection sleeve 20 is interrupted, thus impeding thermal flow between the support element sections 9 and 10 considerably.

In the connection between the support element and the connecting component described above in respect of Fig. 5, SMA members which are simple to produce; can be used. The connection can be used in the case of support elements of small diameter. Simple installation is possible.

All of the embodiments described with reference to Fig. 3, Fig. 4 and Fig. 5 are adequate on their own for maintaining fastening of cryogenic satellite tank in space without the use of additional uninterrupted rigid attachment means. After cooling and thus the resultant loosening of the thermally controllable connection components, the rigidly fastened bridging elements 11 of the connections still provide sufficient dimensional stability.

The bridging element 11 can differ from that comprising thin-walled tubes as described above. These could, for example, be stay-shaped carbon fibre reinforced or glass fibre reinforced components, or the connection between support element sections could be established by plates bonded cross-like to each other, in an axial direction.

As already mentioned above, the SMA members of the embodiments described are made from a NiTiCuFe alloy. The chemical composition of this alloy is selected such that at ambient temperatures as low as 0 degree C, complete austenite is present, and that complete transformation from austenite to martensite is completed above the temperature to be expected in space - typically ranging from approximately 2 K to approximately 220 K.

As described above, the SMA members are subjected to thermomechanical training prior to their use, so as to achieve a two-way effect.

Claims:

1. An attachment device for a cryogenic satellite tank comprising a first member and a second member connected by means of a shape memory alloy (SMA) member, wherein the arrangement of the first member, second member and the SMA member is such that the first and second members are connected when the SMA is in an austenitic state but the connection between the first member and second member is loosened when the SMA expands in its martensitic state following cooling in space, resulting in reduced surface pressure and reduced surface contact, so that thermal flow between the first member and the second member is reduced.

2. An attachment device as claimed in Claim 1, wherein the SMA element is a bolt and the second member has pre-tensioned springs which act under the expansion of the SMA element to move the first member and second member away from each other.

3. An attachment device according as claimed in Claim 1, wherein an intermediate member is arranged between the first and second member, and the SMA member connects the first and second members via the intermediate member.

4. An attachment device as claimed in Claim 3, wherein the SMA member is a bolt and the intermediate member is attached to a sleeve which is attached to the first and second members, the intermediate member being connected to the sleeve by means of a further SMA member so that, on cooling of the further SMA member, the second member moves away from the intermediate member but the sleeve remains rigidly connected to the first member.

5. An attachment device for a cryogenic satellite tank comprising a first member and a second member connected by means of a shape memory alloy (SMA) member, wherein the first member comprises two parts connected by a

thermally-controlled connection, and the arrangement of the first member, second member and the SMA member is such that the first and second members are connected when the SMA is in an austenitic state but the connection between the first member and second member is loosened when the SMA expands in its martensitic state following cooling in space, resulting in reduced surface pressure and reduced surface contact, so that thermal flow between the first member and the second member is reduced.

6. An attachment device as claimed in Claim 5, wherein the first member is in the form of a tube, the second member is connected to one of the first member parts, the first member parts are rigidly connected to one another by means of a bridging member having poor thermal conductivity, and the thermally-controlled connection is in the form of an SMA member arranged between the parts of the first member, the SMA member being able to transmit forces of greater magnitude than the bridging element.

7. An attachment device as claimed in Claim 6, wherein the thermally-controlled connection comprises an axially acting stud bolt connection having a stud bolt sleeve attached to one part of the first member and engageable with at least one stud bolt, a split taper socket attached to the other part of the first member and engageable with at least one clamping ring, the engagement of the split taper socket and the clamping ring being in the manner of a conical tongue and groove connection, through-holes for attachment of a free end of the at least one stud bolt, SMA members in the form of bolts for contraction of the clamping ring, and an SMA ring so that, on cooling, the conical tongue and groove connection between the clamping ring and the split taper socket is released as a result of expansion of the SMA ring and SMA members.

8. An attachment device as claimed in Claim 6, wherein the thermally-controlled connection comprises a split taper socket having a first snap ring sleeve attached to one part of the first member, a second snap ring sleeve attached to the other

part of the first member and an SMA member in the form of a split ring taper socket, the SMA member engaging snap ring grooves of the first and second snap ring sleeves by means of corresponding projections, the projections being released from the snap ring sleeves as a result of expansion of the SMA member on cooling.

9. An attachment device as claimed in Claim 6, wherein the thermally-controlled connection comprises an axially acting screw connection having connection sleeves engageable with the first and second parts of the first member respectively, the connection sleeves having flange-like arched end surfaces with holes for engagement of SMA members in the form of bolts, so that the connection is loosened as a result of expansion of the SMA members on cooling so that the connection sleeves are moved away from one another.

10. An attachment device as claimed in any one of the preceding claims, wherein the SMA members are made of a NiTiCuFe alloy, are thermo-mechanically trained to produce a two-way effect, fully transform to an austenitic state below 0 degree C under the action of heat and, on cooling, fully transform to a martensitic state above the expected service temperature in space.

11. An attachment device as claimed in Claim 7, wherein the SMA ring is made of a NiTiCuFe alloy, is thermo-mechanically trained to produce a two-way effect, fully transforms to an austenitic state below 0 degree C under the action of heat and, on cooling, fully transforms to a martensitic state above the expected service temperature in space.

12. An attachment device for a cryogenic satellite tank substantially as herein described with reference to any one of the embodiments shown in the accompanying drawings.

Application No:	GB 0017640.4	**Examiner:**	David Glover
Claims searched:	1-12	**Date of search:**	28 November 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): E2A (AGC, AGKFH, AGKFM, AGKX, AGMD, AGME, AGMK, AGX); F2G (G2A)

Int Cl (Ed.7): F16B 1/00, 2/00, 2/02, 2/06, 4/00, 35/00; F16L 21/00, 25/00

Other: Online: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	WO91/09246	(Raychem) see particularly page 8 line 24 to page 9 line 4	1, 5, 6, 8
X	JP 040069491	(Toshiba) see English language PAJ abstract	1, 5-7
X	US 5535815	(USA Secretary of the Navy) see particularly column 2 line 35 to column 3 line 46	1-5

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.